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Analysis of the interaction between particles and gliding arc discharge in a spouted bed reactor

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Abstract. In this paper, the interaction between particles and gliding arcs in a spouted bed reactor combined with gliding arc discharge was investigated using a high-speed camera. Based on the images captured by the camera, we evaluated the retention time for gliding arcs, the contact frequency of particles with the gliding arc, and the passage area of the gliding arc until its disappearance. The effects of the gas flow rate; electrode angle, which is same as the cone angle of the spouted bed; and applied voltage of gliding arcs were investigated. The retention time for gliding arcs was extended by a high applied voltage, the passage area was increased at a high gas flow rate, and the contact frequency was increased by decreasing the electrode angle. The results obtained here can support the optimization of particle treatment processes in a spouted bed with gliding arc discharge.

1 Introduction

Gliding arcs are created by applying a high voltage between a pair of electrodes in the presence of a gas flow, which makes gliding arc discharge cyclic. More specifically, the process of gliding arc discharge is repetitive, which is discussed as follows. When the applied voltage reaches critical value for gas breakdown, an arc is generated at the shortest gap distance between the electrodes. The gas flow pushes the arc in the flow's direction along the electrode until it disappears before a new arc is recreated at the first point [1]. Gliding arc discharge has unique characteristics. When an arc is generated at the first point, it has a high temperature and activity similar to those of thermal plasma. However, the arc moves with the flow of gas, and its properties changes to those of low temperature plasma [1]. Due to the fact that arcs do not get extremely hot, we can perform experiments with it using simple equipment. Gliding arcs can also be created at atmospheric pressure.

Spouted beds are a kind of typical equipment for particle processes, and they provide excellent particle mixing as well as high heat and mass transfer s in the bed. In our previous study, we suggested that a spouted bed reactor combined with gliding arc discharge had a potential for particle modification and coating, in which polymer based particles were coated with zinc [2]. There are some studies on the characteristics and shapes of gliding arc discharge [3, 4]. However, few studies are available on the behavior of gliding arc discharge in a spouted bed. The interaction between gliding arcs and particles in a spouted bed has not been clarified yet. Therefore, in this study, the effects of particle presence, gas flow rate, electrode angle, and applied voltage on the behaviors of arcs and particles in a spouted bed combined with gliding arc discharge were evaluated.

2 Material and methods

2.1 Experimental set up

A schematic of the gliding arc discharge reactor is shown in Figure 1. The shape of the reactor is slot-rectangular, and its thickness is 3 mm. The electrodes were aligned with the reactor; thus, the electrode angle became similar to the cone angle. In this experiment, the applied voltage was measured using an oscilloscope (TBS 1042 and TDS 754D Tektronix Corporation). We used a ferromagnetic transformer (50 Hz; LECIP Corporation) as the power supply for generating gliding arcs. The behaviors of the arcs and particles were captured using a high-speed camera (MEMRECAM fx-K4, nac Corporation) which can take pictures at 5,000 frames per second with a shutter speed of 200 μs.

2.2 Materials

Poly methyl methacrylate (PMMA, WAKO-Chemicals Corporation.) with an average diameter of 0.6 mm was used as spouted particles. Argon was selected as the plasma operating gas because it can easily generate arcs and it has an inert nature. A zinc wire with a diameter of 1.0 mm (Nilaco Corporation) was used as the electrode.

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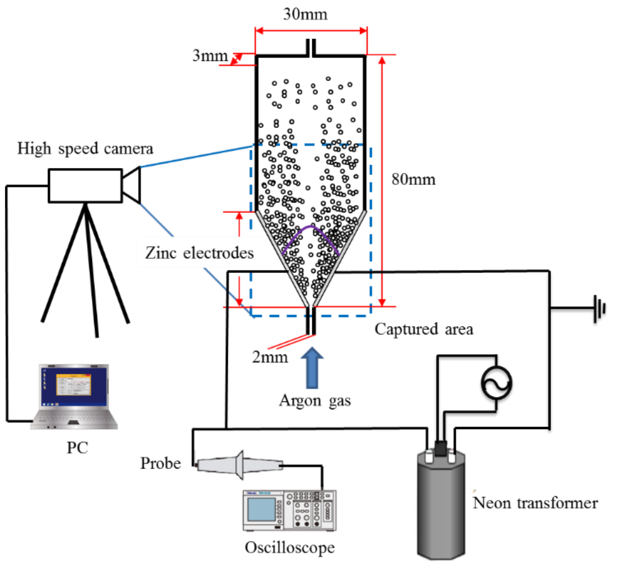


Figure 1. Experimental setup.

2.3 Analysis method

The passage area of a moving arc was defined as the area surrounded by the arc and the electrodes. The area where a gliding arc moved was evaluated using the first and last photos of one discharge. In addition, the length of the arc until its disappearance was measured. The time from the formation of an arc until its disappearance was defined as the arc discharge retention time. The number of particles that an arc can touch from its formation until its disappearance was defined as its contact frequency with particles. The effects of the gas flow rate, electrode angle, and applied voltage of the gliding arc were investigated. The experimental conditions are shown in Tables 1 and 2.

Table 1. Experimental parameters for measurements of passage area, retention time, and arc length.

Ar gas flow rate [L/min]	2.0, 3.0, 4.0
Electrode angle [°]	30, 35, 40, 45, 50
Applied voltage [kV]	3.0, 4.5, 6.0
PMMA loading [g]	0, 0.3

Table 2. Experimental parameters for measurements of contact frequency.

Ar gas flow rate [L/min]	3.0, 3.5, 4.0
Electrode angle [°]	30, 40, 50
Applied voltage [kV]	6.0
PMMA loading [g]	0.1

3 Results and discussion

3.1 Shape of gliding arcs

The photos of gliding arc discharges without and with PMMA particles are shown in Figures 2 and 3, respectively. By comparing these figures, the shapes of the arcs were varied by the existence of particles, which could rectify the gas flow inside the reactor.

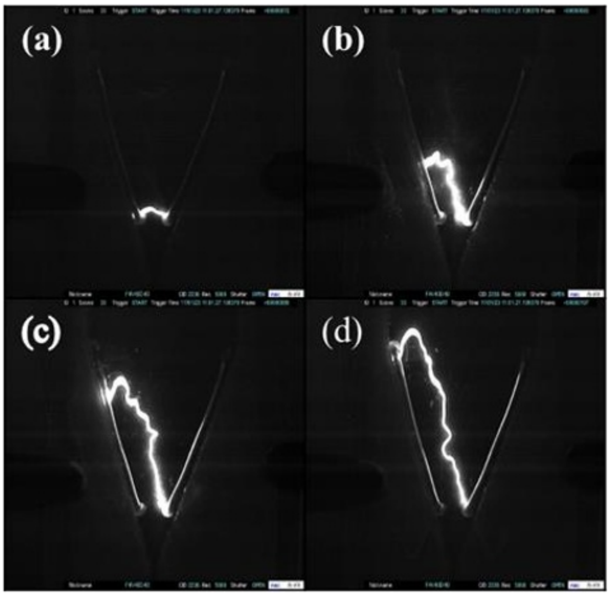


Figure 2. Photos of the gliding arc discharge without PMMA particles under the following conditions: gas flow rate, 4.0 L/min; voltage, 6.0 kV; electrode angle, 40°. (a) 0 s, (b) 0.0022 s, (c) 0.0044 s, and (d) 0.0066 s. All figures show one cycle of discharge.

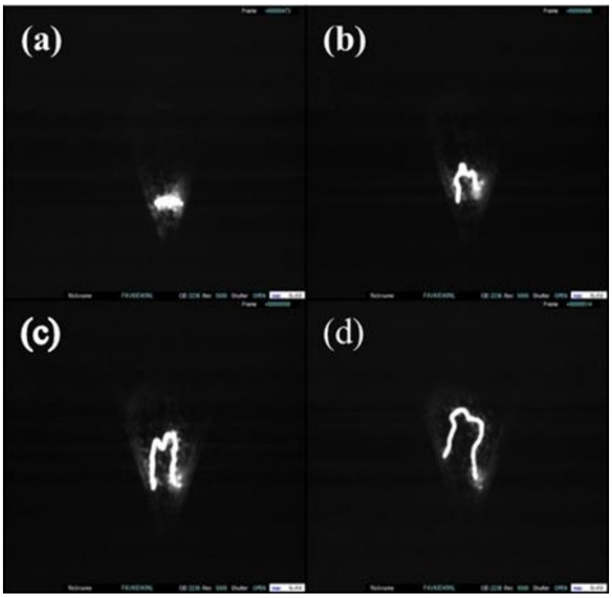


Figure 3. Photos of the gliding arc discharge in the presence of PMMA particles under the following conditions: gas flow rate, 4.0 L/min; voltage, 6.0 kV; electrode angle, 40°. (a) 0 s, (b) 0.0028 s, (c) 0.0056 s, and (d) 0.0084 s. All the figures show one cycle of discharge

3.2 Passage area of gliding arc

Figure 4 shows the passage area by changing electrode angle, flow rate, and voltage with PMMA particles. The area increased by increasing the gas flow rate and applied voltage. However, it exhibited a peak at around 40°–45° because the arc is likely to disappear at a lower position where the distance between the electrodes is wider at a larger electrode angle.

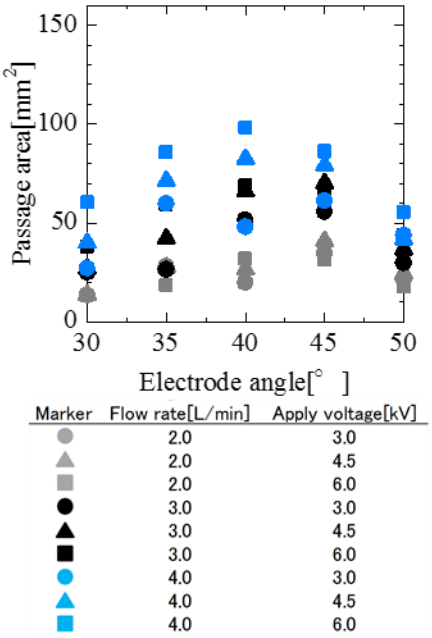


Figure 4. Passage area with the change of the electrode angle, gas flow rate, and voltage in the presence of PMMA particles.

3.3 Retention time of gliding arcs

The retention time without and with PMMA particles is shown in Figures 5 and 6, respectively. When the gas flow rate increased, the time of gliding arcs decreased without the particles.

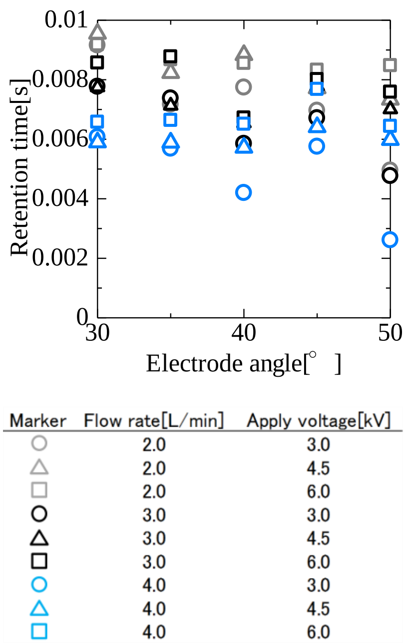


Figure 5. Arc retention time with the change of the electrode angle, gas flow rate, and voltage in the absence of PMMA particles.

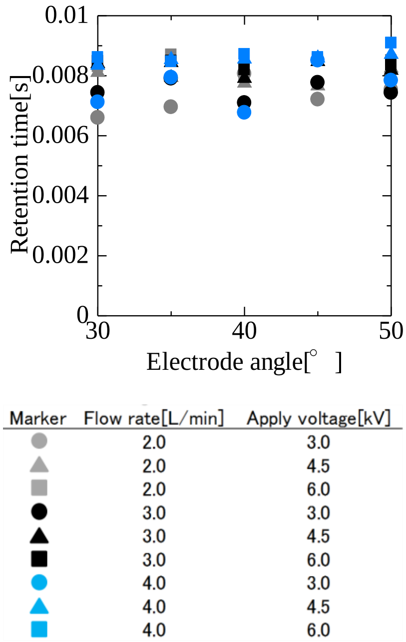


Figure 6. Arc retention time with the change of the electrode angle, gas flow rate, and voltage in the presence of PMMA particles.

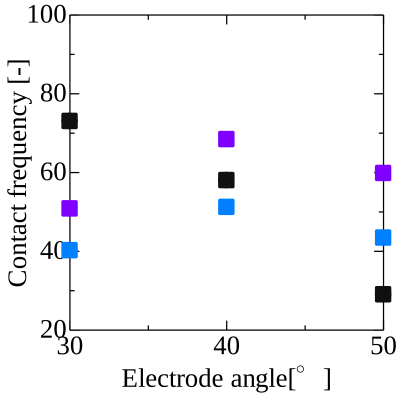
In contrast, the time was almost constant with the particles. It is known that when the length of a gliding arc exceeds its critical value, the heat loss from the plasma column begins to exceed the energy supplied by the source, resulting in the elimination of the gliding arc [1]. The arc length at 4.0 L/min, 40°, and 6.0 kV is shown in Table 3. The critical length of the arc was almost the same regardless of the presence of particles (Table 3). As shown in Figure 4, the retention time was extended by introducing the particles. Thus, the combination of a spouted bed with gliding arc discharge is suitable from the viewpoint of providing an active reaction field.

Table 3. Gliding arc length at 4.0 L/min, 40°, and 6 kV.

	without particles	with particles
Length of the arc [mm]	39.6	40.0

3.4 Contact frequency of particles with the gliding arc

The contact frequency of arcs and particles is shown in Figure 7. The frequency exhibited a maximum electrode angle of around 40° under high gas flow rate conditions, similar to the trend of the passage area, as shown in Figure 4. However, the frequency at the smallest electrode angle showed the highest value at a gas flow rate of 3.0 L/min because particle circulation seemed insufficient, resulting in a high density of particles near the bottom of the reactor.



Marker	Flow rate [L/min]	Applied voltage [kV]
■ (black)	3.0	6.0
■ (purple)	3.5	6.0
■ (blue)	4.0	6.0

Figure 7. Contact frequency of particles with gliding arcs.

4 Conclusion

The interaction between particles and gliding arcs in a spouted bed reactor combined with gliding arc discharge was investigated. Analyses of the photos taken using a high-speed camera indicated that the behaviors of arcs and particles were affected by the electrode angle, gas flow rate, and discharge voltage. In particular, the passage area of gliding arcs increased by increasing the applied voltage and gas flow rate. From the analysis of contact frequency, the interaction of gliding arcs and particles depended on the shape of the reactor. The results suggested that the reactor proposed in this study can be applied for particle surface treatment efficiently.

References

[1] Fridman A., Nester, S., Kennedy, LA., Saveliev, A., Mutaf-Yardimci, O., “Gliding arc gas discharge”, Progress in energy and combustion science 25, 1999, 211-231
[2] Ua-amnueychai,W., Kodama, S., Tanthapanichakoon, W., Sekiguchi, H., “Preparation of zinc coated PMMA using solid precursor by gliding arc discharge”, Chem Eng. J., 278, 2015, 301-308
[3] Zhu, J. et al, “Measurements of 3D slip velocities and plasma column lengths of a gliding arc discharge”, Appl. Phys. Let., 4, 2015
[4] Richard, F, Cormier, JM., Pellerin, S., Chapelle, J., “Physical study of a gliding arc discharge”, Appl. Phys. Let., 79, 1996, 2245-2250